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Based on comparisons with buoy data, the wind speed and wave height measured by satellite altimeters are in excellent agreement with in-situ measurements. In regions of low swell effects, the combination of wind speed and wave height further yields the information of wave period. The long-term monitoring of these wave parameters from satellite altimeters can be used to study the wave climate of the world oceans. Examples from application to the Gulf of Mexico and the Yellow and East China Seas are presented. Using three years of TOPEX/POSEIDON continuous data, the annual and seasonal maps of the wind and wave climatology of the two regions can be constructed. Many mesoscale features can be clearly identified, and the geometric effects on the wave pattern can be seen from the wind and wave distributions.

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Remote Sensing -- A Scientific Vision for Sustainable Development

CLIMATOLOGY OF WIND AND WAVES FROM SATELLITE ALTIMETERS

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Abstract – Based on comparisons with buoy data, the wind speed and wave height measured by satellite altimeters are in excellent agreement with in-situ measurements. In regions of low swell effects, the combination of wind speed and wave height further yields the information of wave period. The long-term monitoring of these wave parameters from satellite altimeters can be used to study the wave climate of the world oceans. Examples from application to the Gulf of Mexico and the Yellow and East China Seas are presented. Using three years of TOPEX/POSEIDON continuous data, the annual and seasonal maps of the wind and wave climatology of the two regions can be constructed. Many mesoscale features can be clearly identified, and the geometric effects on the wave pattern can be seen from the wind and wave distributions.

INTRODUCTION

Satellite remote sensing provides an efficient way for monitoring global and regional oceanographic parameters. Spaceborne altimeters following their many generations of development have provided high-quality data on the sea state with an unusually high spatial density. For example, TOPEX/POSEIDON (hereafter referred to as TOPEX) provides wind and wave information every second, corresponding to approximately a 7-km resolution along the satellite tracks. The spacing of the tracks is nominally 316 km (127 revolutions per repeat cycle) at the equator and much smaller at higher latitudes. The revisiting period of each track is 9.9156 days [1]. With such high density coverage, we can study the regional wave climatology using the TOPEX altimeter data output of wind and wave parameters. In this paper, the measurement accuracy of the wind and wave parameters from the TOPEX altimeter is validated with in-situ ocean buoy data

COMPARISON OF WIND AND WAVE PARAMETERS FROM ALTIMETERS WITH IN-SITU BUOY DATA

Comparisons of TOPEX significant wave heights (H) and wind speed (U) with in-situ measurements from surface buoys have shown very positive agreement [2-3]. In particular, Ref. [3] presents a comprehensive comparison of wind speed and wave height between the TOPEX altimeters and 14 moored buoys along the west coast of Canada, of which 3 are in the deep ocean, approximately 400 km west of the British Columbia coast; 6 are in the exposed positions within 100 km from the coast, and 5 are in sheltered coastal waters. Detailed statistical comparisons of these three groups of buoys with all three altimeters (NASA Ku- and C-band altimeters and CNES Ku-band solid state altimeter) are performed. Excellent agreement between the altimeter and buoy measurements of the significant wave height is found for the nine buoys in exposed positions. For coastal regions, the agreement is clearly not as good. The large variation in the coastal comparison is attributed to the local variation of the wave conditions due to the close proximity to the shoreline. Ref. [3] further shows that in the exposed locations, the rms data scatter is greatly reduced when the spatial distance between TOPEX and buoy observations is reduced to 10 km. For the three outer buoys and 6 inner buoys, the rms differences in wave height reduce to 0.14 and 0.15 m, respectively.

The excellent agreement on the wave height measurement is also confirmed in the Gulf of Mexico stations. A detailed statistical comparison of 6 data sets in the Gulf of Mexico is presented in [4]. The results pertaining to the three key properties of a wave field, the significant wave height, significant wave period and wind speed, are shown in Figs. 1a-c, which display the comparisons of the significant wave height, wind speed and characteristic (average) wave period derived from the TOPEX Ku-band altimeter and NDBC buoy. Only data points within 10 km spatial lags are used. The measurements from the two systems are essentially equivalent. The average ratio and one standard deviation of the wave heights, wind speeds, and characteristic wave periods are 1.01 ± 0.14, 0.95 ± 0.11, 1.06 ± 0.13, respectively. The distributions of these ratios are displayed in Figures 1d-f, showing very narrow spreading.

WIND AND WAVE CLIMATOLOGY

Gulf of Mexico (GoM)

There are fourteen ground tracks from TOPEX in the GoM. The wind speed and wave height derived from the altimeters can be used to construct synoptic views of the regions. In addition, wave period and large scale surface steepness due to wave motion can be calculated from the wind speed and wave height parameters. In forming the climatological maps, the TOPEX data are averaged over one-degree squares. TOPEX data from one or more tracks that fall within any part of a square are used in the average for that square. The TOPEX data have high spatial resolution of about 7 km along track. The across-tracks (approximately 300 km) and temporal (10 days repeat cycle) resolutions are relatively coarse, so the shortest averaging period used at this stage is 90 days. The results reveal the seasonal and annual variations of the wind and wave climate in the regions [5]. Fig. 2 shows an example of the three-month (January to March, 1994) average of the wind speed, wave height, wave period and wave steepness in the GoM. Other seasons, and annual as well as three-year averages are also processed but not shown here. A few common features of the wind and wave climate in the GoM include: (1) The long-term average of the mean wave height increases from east to west. For example, the wave height

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range of the three-year average is from 0.5 m off the coast of Florida to 1.5 m off the coast of Texas. Similarly, mean wind speed, wave period and wave steepness show a trend of increasing from east to west. (2) Superimposed on the westward increasing trend, there is an oscillatory components, such that there are one to two local maximum values of the wind and wave parameters in the longitudinal direction. The length scale of the oscillatory component is on the order of 300 to 600 km.

The GoM is a deep (more than 4000 m in the deepest region) semi-enclosed sea with the opening in the SE corner. Although the entrance to the GoM is partially blocked by the islands of Cuba and the Yucatan Peninsula, the Equatorial Current enters the GoM through the Caribbean Sea and Yucatan Channel, forming the Loop Current with a transport of approximately 30×10^6 m^3/s. The Loop Current traces an anticyclonic path and exits the GoM through the Florida Straits and eventually becomes a principal component of the Gulf Stream [7]. Frequently, eddies are shedded from the Loop Current and propagate westward. The Loop Current in the gulf forms a very dynamic and active region. From examining the seasonal, annual and three-year average of the climatology maps, it is found that one of the dominant locations of the local highs is near the center of the eastern gulf in the area of Loop Current instabilities [6]. This local high is relatively stationary (compare the three-month average in Fig. 2 and the three-year average in Fig. 3) and may be an indication of active air-sea interactions in the region of the Loop Current instabilities.

Yellow and East China Seas (YES)

In the YES, there are seven TOPEX tracks passing through the region. The same procedure to construct the climatology maps of the GoM is applied to the YES. Fig. 4 shows an example of the three-month average (January to March, 1994) wind and wave climatology, which is distinctively different from that in the Gulf of Mexico. The distribution of the wind speed or wave parameters is almost stratified and follow closely the local bathymetry. For the long-term average, a north-south stratification of the distribution is evident (Fig. 5 shows an example of the 1994 averages). The oscillatory component is much weaker.

The YES are on a large and shallow continental shelf, with depths less than 100 m on the shelf. The major current system in the region is the Kuroshio, which enters YES just southeast of Taiwan and exits from southwest of Japan. The main axis of the Kuroshio is usually just outside of the 200 m contour line. The Kuroshio may intrude onto the shelf through two major regions. The first is through the Taiwan Strait during the winter months when the Taiwan Warm Current is weak [8]. The second source is the branching of the Tsushima Current from the Kuroshio [9] and the subsequent intrusion of the Yellow Sea Warm Current northward into the Yellow Sea [10]. One of the driving forces of the Yellow Sea Warm Current and the flux of open ocean properties onto the continental shelf is the northerly wind bursts during the winter season. Due to the shallow water depth, the wind events are capable of creating large sea level changes, which produce horizontal pressure gradients that drive the subsurface currents [11].

Interestingly, the ranges of wind speeds, wave heights, waver periods and wave steepnesses in the GoM and YES are quite similar (compare Figs. 2-3 with Figs. 4-5). The dynamic processes and the circulation patterns in the two regions are obviously different. These may contribute to the very different climatology of wind and waves in the two regions.

SUMMARY AND CONCLUSIONS

Using the TOPEX altimeter output of wind speed and wave height, the regional distributions of the wind and wave characteristics in the Gulf of Mexico and in the Yellow and East China Seas are investigated. The distributions of wind and wave parameters in the Gulf of Mexico is characterized by an oscillatory mode in the longitudinal direction. The Loop Current appears to have a strong influence on the dynamics of the region; this effect shows up in the presence of a stationary local high in the distributions of wind speeds, wave heights, wave periods and wave steepnesses. In the Yellow and East China Sea, although the ranges of wind and wave parameters are very similar to those observed in the Gulf of Mexico, the climatology of the region is predominately a stratified distribution in the north-south orientation, and closely follows the local bathymetry.

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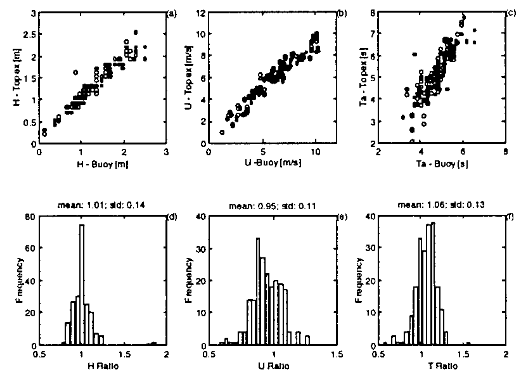

Fig. 1. Comparison of the altimeter and buoy measurements of the significant wave height (a), wind speed (b), and average wave period (c). The ratios (TOPEX divided by buoy) of these three wave parameters are shown in (d), (e) and (f), respectively [4].

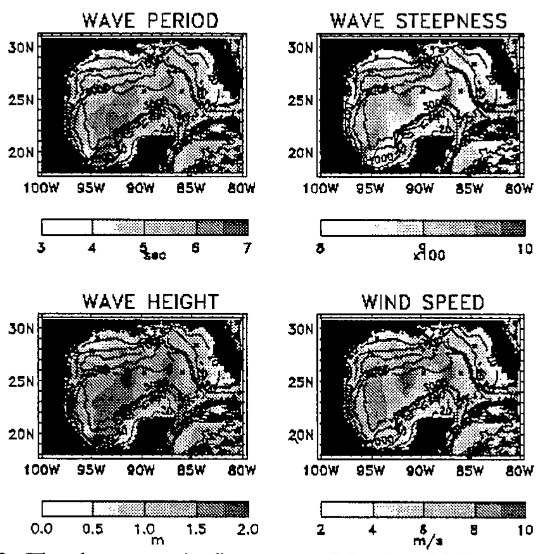

Fig. 2. The three-month (January to March, 1994) average of the wind and wave climatology in the Gulf of Mexico.

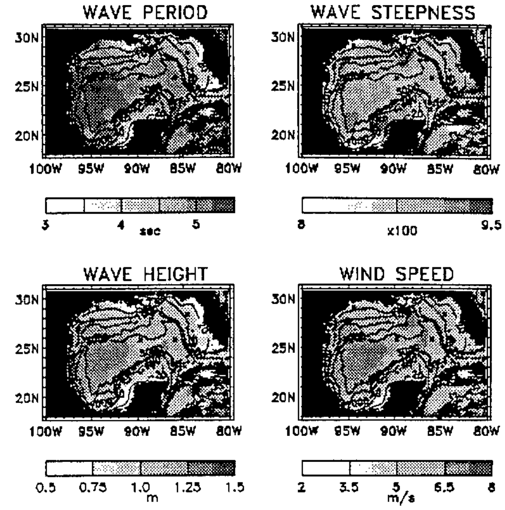

Fig. 3. The three-year (93-95) average of the wind and wave climatology in the Gulf of Mexico.

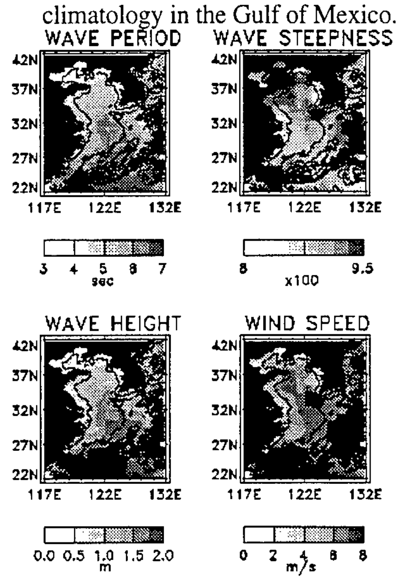

Fig. 4. The three-month (January to March, 1994) average of the wind and wave climatology in the Yellow and East China Seas.

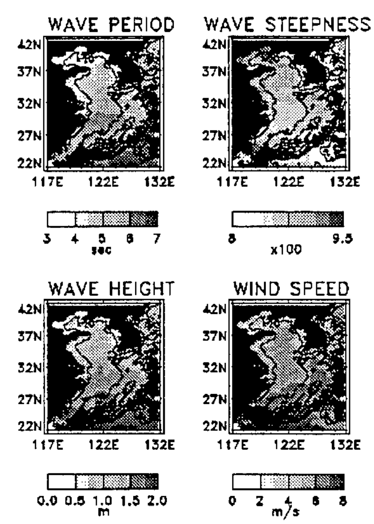

Fig. 5. The annual average (1994) of the wind and wave climatology in the Yellow and East China Seas.